

WHAT IS CLAIMED IS:

1. A method of treating a hydrocarbon containing formation in situ, comprising:
 - 5 providing heat from one or more heat sources to at least one portion of the formation;
 - allowing the heat to transfer from the one or more heat sources to a selected section of the formation;
 - controlling the heat from the one or more heat sources such that an average temperature within at least a majority of the selected section of the formation is less than about 375 °C; and
 - 10 producing a mixture from the formation.
2. The method of claim 1, wherein the one or more heat sources comprise at least two heat sources, and wherein superposition of heat from at least the two heat sources pyrolyzes at least some hydrocarbons within the selected section of the formation.
3. The method of claim 1, wherein controlling formation conditions comprises maintaining a temperature within the selected section within a pyrolysis temperature range.
4. The method of claim 1, wherein the one or more heat sources comprise electrical heaters.
5. The method of claim 1, wherein the one or more heat sources comprise surface burners.
- 25 6. The method of claim 1, wherein the one or more heat sources comprise flameless distributed combustors.
7. The method of claim 1, wherein the one or more heat sources comprise natural distributed combustors.

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wherein P_{wr} is the heating energy/day, h is an average heating rate of the formation, ρ_B is formation bulk density, and wherein the heating rate is less than about 10 °C/day.

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5 2127. The method of claim 2117, wherein allowing the heat to transfer comprises transferring heat substantially by conduction.

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2128. The method of claim 2117, wherein providing heat from the one or more heat sources comprises heating the selected section such that a thermal conductivity of at least 10 a portion of the selected section is greater than about 0.5 W/(m °C).

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2129. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons having an API gravity of at least about 25°.

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15 2130. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, and wherein about 0.1 % by weight to about 15 % by weight of the condensable hydrocarbons are olefins.

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20 2131. The method of claim 2117, wherein the produced mixture comprises non-condensable hydrocarbons, and wherein a molar ratio of ethene to ethane in the non-condensable hydrocarbons ranges from about 0.001 to about 0.15.

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25 2132. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 1 % by weight, when calculated on an atomic basis, of the condensable hydrocarbons is nitrogen.

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2133. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 1 % by weight, when calculated on an atomic basis, of the condensable hydrocarbons is oxygen.

2134. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 1 % by weight, when calculated on an atomic basis, of the condensable hydrocarbons is sulfur.

5 2135. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, wherein about 5 % by weight to about 30 % by weight of the condensable hydrocarbons comprise oxygen containing compounds, and wherein the oxygen containing compounds comprise phenols.

10 2136. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, and wherein greater than about 20 % by weight of the condensable hydrocarbons are aromatic compounds.

15 2137. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 5 % by weight of the condensable hydrocarbons comprises multi-ring aromatics with more than two rings.

20 2138. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 0.3 % by weight of the condensable hydrocarbons are asphaltenes.

25 2139. The method of claim 2117, wherein the produced mixture comprises condensable hydrocarbons, and wherein about 5 % by weight to about 30 % by weight of the condensable hydrocarbons are cycloalkanes.

Sub C6 2140. The method of claim 2117, wherein the produced mixture comprises a non-condensable component, wherein the non-condensable component comprises hydrogen, wherein the hydrogen is greater than about 10 % by volume of the non-condensable component, and wherein the hydrogen is less than about 80 % by volume of the non-condensable component.

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2141. The method of claim 2117, wherein the produced mixture comprises ammonia, and wherein greater than about 0.05 % by weight of the produced mixture is ammonia.

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2142. The method of claim 2117, wherein the produced mixture comprises ammonia, and wherein the ammonia is used to produce fertilizer.

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2143. The method of claim 2117, further comprising controlling a pressure within at least a majority of the selected section of the formation, wherein the controlled pressure is at least about 2.0 bar absolute.

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2144. The method of claim 2117, further comprising controlling formation conditions to produce the mixture, wherein a partial pressure of H₂ within the mixture is greater than about 0.5 bar.

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2145. The method of claim 2144, wherein the partial pressure of H₂ within the mixture is measured when the mixture is at a production well.

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2146. The method of claim 2117, further comprising altering a pressure within the formation to inhibit production of hydrocarbons from the formation having carbon numbers greater than about 25.

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2147. The method of claim 2117, further comprising controlling formation conditions by recirculating a portion of hydrogen from the mixture into the formation.

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2148. The method of claim 2117, further comprising:
providing hydrogen (H₂) to the heated section to hydrogenate hydrocarbons within the section; and
heating a portion of the section with heat from hydrogenation.

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2149. The method of claim 2117, further comprising:
producing hydrogen and condensable hydrocarbons from the formation; and

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~~hydrogenating a portion of the produced condensable hydrocarbons with at least a portion of the produced hydrogen.~~

2150. The method of claim 2117, wherein allowing the heat to transfer comprises
5 increasing a permeability of a majority of the selected section to greater than about 100 millidarcy.

2151. The method of claim 2117, wherein allowing the heat to transfer comprises
substantially uniformly increasing a permeability of a majority of the selected section.

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2152. The method of claim 2117, further comprising controlling the heat to yield greater than about 60 % by weight of condensable hydrocarbons, as measured by the Fischer Assay.

2153. The method of claim 2117, wherein producing the mixture comprises producing the mixture in a production well, and wherein at least about 7 heat sources are disposed in the formation for each production well.

20 2154. The method of claim 2117, further comprising providing heat from three or more heat sources to at least a portion of the formation, wherein three or more of the heat sources are located in the formation in a unit of heat sources, and wherein the unit of heat sources comprises a triangular pattern.

25 2155. The method of claim 2117, further comprising providing heat from three or more heat sources to at least a portion of the formation, wherein three or more of the heat sources are located in the formation in a unit of heat sources, wherein the unit of heat sources comprises a triangular pattern, and wherein a plurality of the units are repeated over an area of the formation to form a repetitive pattern of units.

30 2156. A method of treating a hydrocarbon containing formation in situ, comprising:
heating a first section of the formation to produce a mixture from the formation;

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~~heating a second section of the formation; and~~

recirculating a portion of the produced mixture from the first section into the second section of the formation to provide a reducing environment within the second section of the formation.

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2157. The method of claim 2156, further comprising maintaining a temperature within the first section or the second section within a pyrolysis temperature range.

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2158. The method of claim 2156, wherein heating the first or the second section comprises heating with an electrical heater.

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2159. The method of claim 2156, wherein heating the first or the second section comprises heating with a surface burner.

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2160. The method of claim 2156, wherein heating the first or the second section comprises heating with a flameless distributed combustor.

2161. The method of claim 2156, wherein heating the first or the second section comprises heating with a natural distributed combustor.

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2162. The method of claim 2156, further comprising controlling a pressure and a temperature within at least a majority of the first or second section of the formation, wherein the pressure is controlled as a function of temperature, or the temperature is controlled as a function of pressure.

2163. The method of claim 2156, further comprising controlling the heat such that an average heating rate of the first or the second section is less than about 1 °C per day during pyrolysis.

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2164. The method of claim 2156, wherein heating the first or the second section comprises:

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heating a selected volume (V) of the hydrocarbon containing formation from one or more heat sources, wherein the formation has an average heat capacity (C_v), and wherein the heating pyrolyzes at least some hydrocarbons within the selected volume of the formation; and

5 wherein heating energy/day provided to the volume is equal to or less than Pwr , wherein Pwr is calculated by the equation:

$$Pwr = h * V * C_v * \rho_B$$

wherein Pwr is the heating energy/day, h is an average heating rate of the formation, ρ_B is formation bulk density, and wherein the heating rate is less than about 10 10 $^{\circ}\text{C}/\text{day}$.

2165. The method of claim 2156, wherein heating the first or the second section comprises transferring heat substantially by conduction.

15 2166. The method of claim 2156, wherein heating the first or the second section comprises heating the first or the second section such that a thermal conductivity of at least a portion of the first or the second section is greater than about 0.5 $\text{W}/(\text{m } ^{\circ}\text{C})$.

20 2167. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons having an API gravity of at least about 25 $^{\circ}$.

25 2168. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, and wherein about 0.1 % by weight to about 15 % by weight of the condensable hydrocarbons are olefins.

2169. The method of claim 2156, wherein the produced mixture comprises non-condensable hydrocarbons, and wherein a molar ratio of ethene to ethane in the non-condensable hydrocarbons ranges from about 0.001 to about 0.15.

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2170. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 1 % by weight, when calculated on an atomic basis, of the condensable hydrocarbons is nitrogen.

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2171. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 1 % by weight, when calculated on an atomic basis, of the condensable hydrocarbons is oxygen.

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2172. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 1 % by weight, when calculated on an atomic

basis, of the condensable hydrocarbons is sulfur.

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2173. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, wherein about 5 % by weight to about 30 % by weight of the condensable hydrocarbons comprise oxygen containing compounds, and wherein the oxygen containing compounds comprise phenols.

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2174. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, and wherein greater than about 20 % by weight of the condensable hydrocarbons are aromatic compounds.

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2175. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 5 % by weight of the condensable hydrocarbons comprises multi-ring aromatics with more than two rings.

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2176. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, and wherein less than about 0.3 % by weight of the condensable hydrocarbons are asphaltenes.

60 ~~5T~~ 2177. The method of claim 2156, wherein the produced mixture comprises condensable hydrocarbons, and wherein about 5 % by weight to about 30 % by weight of the condensable hydrocarbons are cycloalkanes.

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2178. The method of claim 2156, wherein the produced mixture ~~comprises~~ a non-condensable component, wherein the ~~non~~ condensable component comprises hydrogen, wherein the hydrogen is greater than about 10 % by volume of the non-condensable component, and wherein the hydrogen is less than about 80 % by volume of the non-condensable component.

10 62 ~~5T~~ 2179. The method of claim 2156, wherein the produced mixture comprises ammonia, and wherein greater than about 0.05 % by weight of the produced mixture is ammonia.

15 63 ~~5T~~ 2180. The method of claim 2156, wherein the produced mixture comprises ammonia, and wherein the ammonia is used to produce fertilizer.

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2181. The method of claim 2156, further comprising controlling a pressure within at least a majority of the ~~first or second~~ section of the formation, wherein the controlled pressure is at least about 2.0 bar absolute.

20 65 ~~5T~~ 2182. The method of claim 2156, further comprising controlling formation conditions to produce the mixture, wherein a partial pressure of H₂ within the mixture is greater than about 0.5 bar.

25 66 ~~5T~~ 2183. The method of claim 2182, wherein the partial pressure of H₂ within the mixture is measured when the mixture is at a production well.

67 ~~5T~~ 2184. The method of claim 2156, further comprising altering a pressure within the formation to inhibit production of hydrocarbons from the formation having carbon numbers greater than about 25.

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2185. The method of claim 2156, further comprising:
providing hydrogen (H_2) to the first or second section to hydrogenate
hydrocarbons within the first or second section; and
heating a portion of the first or second section with heat from hydrogenation.

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2186. The method of claim 2156, further comprising:
producing hydrogen and condensable hydrocarbons from the formation; and
hydrogenating a portion of the produced condensable hydrocarbons with at least a
portion of the produced hydrogen.

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2187. The method of claim 2156, wherein heating the first or the second section
comprises increasing a permeability of a majority of the first or the second section to
greater than about 100 millidarcy.

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2188. The method of claim 2156, wherein heating the first or the second section
comprises substantially uniformly increasing a permeability of a majority of the first or
the second section.

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2189. The method of claim 2156, further comprising controlling the heat to yield greater
than about 60 % by weight of condensable hydrocarbons, as measured by the Fischer
Assay.

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2190. The method of claim 2156, wherein producing the mixture comprises producing
the mixture in a production well, and wherein at least about 7 heat sources are disposed in
the formation for each production well.

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2191. The method of claim 2156, further comprising providing heat from three or more
heat sources to at least a portion of the formation, wherein three or more of the heat
sources are located in the formation in a unit of heat sources, and wherein the unit of heat
sources comprises a triangular pattern.